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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 8, *Ships and marine technology*, Subcommittee SC 6, *Navigation and ship operations*.

This first edition cancels and replaces ISO/PAS 19697:2014.

Introduction

An electronic inclinometer is an electronic device that provides information about roll period, roll amplitude and the heel angle of the ship. *Electronic inclinometers are intended to support the decision-making process on board in order to avoid dangerous situations, as well as assist in and facilitate maritime casualty investigation*. The requirements in this document take into account human factors, ergonomic principles and advances in technology.

Ships and marine technology — Navigation and ship operations — Electronic inclinometers

1 Scope

This document specifies the performance requirements, methods of testing and test results of electronic inclinometers required by the performance standard, IMO resolution MSC.363 (92), in addition to the general requirements contained in resolution A.694 (17) and is associated with IEC 60945.

The electronic inclinometers provide information about actual heel angle, roll amplitude, roll period to support decision-making process on board in order to avoid dangerous situations, in stability (see Annex A for information), as well as to assist in maritime casualty investigation. The electronic inclinometers are mainly composed of a set of sensors, a signal processor, a display, an input device and an interface to other systems.

It does not apply to the electronic inclinometers installed for purposes which are outside the scope of this document, e.g. monitoring of cargo status.

Where a requirement in this document is different from IEC 60945, the requirement in this document takes precedence.

NOTE All requirements that are extracted from the recommendations of IMO Resolution MSC.363 (92), performance standards for electronic inclinometers, are printed in italics and the resolution and paragraph numbers are indicated in brackets.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60945, *Maritime navigation and radiocommunication equipment and systems — General requirements — Methods of testing and required test results*

IEC 61162-1, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 1: Single talker and multiple listeners*

IEC 61162-2, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 2: Single talker and multiple listeners, high-speed transmission*

IEC 61924-2, *Maritime navigation and radiocommunication equipment and systems — Integrated navigation systems — Part 2: Modular structure for INS — Operational and performance requirements, methods of testing and required test results*

IEC 62288, *Maritime navigation and radiocommunication equipment and systems — Presentation of navigation-related information on shipborne navigational displays — General requirements, methods of testing and required test results*

IMO resolution MSC.191 (79), *Performance standard for the presentation of navigation-related information on shipborne navigational displays*

IMO resolution MSC.252 (83), Performance standards for Integrated Navigation Systems (INS)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp/

3.1
actual heel angle
momentary angle of roll referenced to a levelled ship to port or starboard side

[SOURCE: IMO MSC.363 (92), Par. 3.1]

3.2
analogue type display
display (3.3) that shows *actual heel angle* (3.1), *roll amplitudes* (3.7) and *roll peak hold values* (3.9) in a continuous way, such as by means of an arrow pointer and graduated scale

3.3
digital type display
display (3.3) that shows *actual heel angle* (3.1), *roll amplitudes* (3.7) and *roll peak hold values* (3.9) in the form of numbers

3.4
display
means by which the roll behaviour of the ship and the state of the electronic inclinometer system are presented to an observer

3.5
inspection equipment
equipment for testing the performance of the electronic inclinometer

3.6
reset function for roll peak hold value
function for resetting *roll peak hold values* (3.9) to zero and for recording reset date (month, day and year) and time

3.7
roll amplitude
maximum values of heel angle to port or starboard side

[SOURCE: IMO MSC.363 (92), Par. 3.1]

3.8
roll period
time between two successive maximum values of heel angle on the same side of the ship

[SOURCE: IMO MSC.363 (92), Par. 3.1]

3.9
roll peak hold value
maximum values of *roll amplitude* (3.7) to port or starboard side from the last reset

3.10
rolling
motion around the longitudinal axis of the ship

Note 1 to entry: Positive roll is starboard down.

[SOURCE: IMO MSC.363 (92), Par. 3.1]

3.11
zero crossing method
way for measuring wave period by using a zero crossing which is a point where the sign of a measured value (roll angle) changes

EXAMPLE From positive to negative.

4 Requirements

4.1 General

Users of this document shall note that while attempting to implement the requirements, they shall ensure compliance with such statutory requirements, rules and regulations so as to be applicable to the individual ship concerned.

4.2 Functionality

[IMO MSC.363 (92) Par. 1.2] *The electronic inclinometers* shall *in a reliable form*

a) *determine the actual heel angle with the required accuracy,*

b) *determine the roll amplitude with the required accuracy,*

c) *determine the roll period with the required accuracy,*

d) *present the information on a bridge display, and*

e) *provide a standardized interface to instantaneous heel angle to the voyage data recorder (VDR).*

4.3 Information

4.3.1 Actual heel angle and roll amplitude

[IMO MSC.363 (92) Par. 4] *Electronic inclinometers* shall *be capable of measuring the actual heel angle and determining the amplitude of the rolling oscillation of the ship over a range of ±90°*.

4.3.2 Roll period

[IMO MSC.363 (92) Par. 5] *Electronic inclinometers* shall *be capable of measuring the time between the maximum values of the rolling oscillation and determining the roll period over a minimum range of 4 s to 40 s*.

If enough precision is not attained, the period may be measured by the "zero crossing method".

4.3.3 Roll peak hold value

Electronic inclinometers may optionally record the roll peak hold values on both sides and present them on any kind of display.

If optional recording of the roll peak hold values is provided, electronic inclinometers shall have a mean of manually resetting the roll peak hold values by a single operator action.

If necessary, the following sentences may be provided for the reset of roll peak hold value:

$–TXT,01,01,01,EI_RPHVReset_yyyy_mm_dd_oo_nn_ss*hh < CR > < LF > (see IEC 61162-1) where:

— “yyyy” is the reset year;

— “mm” is the reset month;

— “dd” is the reset day;

— “oo” is the reset hour;

— “nn” is the reset minute;

— “ss” is the reset second;

— “hh” is the check sum;

— TXT (see IEC 61162–1).

4.4 Display

[IMO MSC.363 (92) Par. 7.2] *The actual heel angle to port or starboard shall be indicated in an analogue form between the limits of ±45°*. When the actual heel angle exceeds 45° to either side, the analogue display is permitted to remain at 45°.

[IMO MSC.363 (92) Par. 7.1.2] *Electronic inclinometers* shall *display the roll amplitude to both port and starboard side with a minimum resolution of 1°*.

Electronic inclinometers may optionally display the roll peak hold value for both sides, port and starboard, with a minimum resolution of 1°. They may also optionally display its reset date/time or relative time from the reset, if the roll peak hold value function is installed.

[IMO MSC.363 (92) Par. 7.1.1] *Electronic inclinometers* shall *display the latest roll period with a minimum resolution of 1 s*.

[IMO MSC.363 (92) Par. 7.3] *The display may be implemented as a dedicated display or integrated into other bridge systems*.

4.5 Alerts

Electronic inclinometer may provide operational alerts as described in 4.5.1 and shall provide functional alerts as described in 4.5.2.

The alerts shall conform to protocol requirements of [IMO MSC.252 (83)] as specified in IEC 61924-2. The presentation of alerts shall conform to the presentation requirements of [IMO MSC.191 (79)] as specified in IEC 62288.

[IMO MSC.363 (92) Par. 10.2] *Electronic inclinometers* shall *have a bidirectional interface to facilitate communication, to transfer alerts from inclinometers to external systems, and to acknowledge and silence alerts from external systems*.

All alerts provided in the electronic inclinometer shall be output via alert communications interface.

The following sentences shall be provided for the alert communications interface.

Sentences transmitted by the electronic inclinometers:

— ALC and ALF (see IEC 61924-2).

Sentences received by the electronic inclinometers:

— ACN (see IEC 61924-2).

When an Integrated Navigation System (INS) is fitted, a suitable interface shall be provided for CAM-HMI with the Integrated Navigation System [IMO Res. MSC.252 (83) and IEC 61924-2].

4.5.1 Operational alerts

[IMO MSC.363 (92) Par. 8.2] *Electronic inclinometers may optionally provide a warning for indicating that a set heel angle had been exceeded*.

The alert on heel angle excess shall be classified as CAT B Warning. The electronic inclinometer shall have a method of manually setting the threshold value of heel angle excess. The warning is initiated and its warning state becomes “active – unacknowledged”, when the measured heel angle exceeds the threshold value of heel angle excess. The electronic inclinometer shall have the means to acknowledge the alert on heel angle excess. If the alert is not acknowledged, it shall be repeated as warning within 5 min. Once the warning state becomes “active – acknowledged”, the warning state shall not be returned to “normal” automatically regardless of the measured value. The electronic inclinometer shall have a method of changing the alert state from “active – acknowledged” to “normal”.

ALF sentence is used to initiate a warning on other bridge systems when the actual heel angle exceeds the pre-set threshold.

The following sentence may be provided for the input of a threshold value of heel angle excess:

$–TXT,01,01,01,EI_SetRollThresholdAngle_xx_deg *hh < CR > < LF >

and the sentence for transmitting the pre-set value of the threshold:

$–TXT,01,01,01,EI_RollThresholdAngle_xx_deg *hh < CR > < LF >

where:

— “xx” is the threshold value of heel angle;

— “hh” is the check sum;

— TXT (see IEC 61162–1).

Also, the following sentence may be provided for changing the alert state from “active acknowledged” to “normal”:

$–TXT,01,01,01,EI_ChangeToNnormalState*hh < CR > < LF >

where:

— “hh” is check sum;

— TXT (see IEC 61162–1).

NOTE The usual alert handling may not be appropriate in this document. According to the usual alert handling, a state of the warning “active acknowledged” becomes “normal” automatically when the measured heel angle becomes lower than the threshold. However, the measured heel angle changing cyclically in starboard side or port side causes frequent initiation of alerts because a state of warning “active acknowledged” becomes “normal” just after acknowledged and the alert initiated again when the ship rolls to the other side and the measured roll angle exceeds the threshold.

4.5.2 Functional alerts

[IMO MSC.363 (92) Par. 9.1] *Electronic inclinometers* shall *internally check and indicate to the user if all components are operative and if the information provided is valid or not.*

All functional alerts should be classified as CAT.B Warning.

An alert shall be provided on the following conditions:

— malfunction of the electronic inclinometer sensor(s);

— failure of the power supply;

— heel angle data is invalid.

4.6 Interface

[IMO MSC.363 (92) Par. 10.1] *Electronic inclinometers* shall *comprise a digital interface providing actual heel angle information to other systems like, e.g. the voyage data recorder (VDR), with an update rate of at least 5 Hz. Electronic inclinometers* shall *also comprise a digital interface providing the displayed information of roll period and roll amplitude* (see 4.3).

[IMO MSC.363 (92) Par. 10.3] *The digital interface* shall *comply with the relevant International Standards* IEC 61162-2 as amended.

The sentence for transmitting the data to VDRs and other external systems is described in Annex C provisionally.

4.7 Power supply

[IMO MSC.363 (92) Par. 12] *Electronic inclinometers* shall *be powered from the ship's main source of electrical energy. In addition, it* shall *be possible to operate the electronic inclinometers from the ship's emergency source of electrical energy*.

5 Accuracy

5.1 Actual heel angle, roll amplitude and roll period

[IMO MSC.363 (92) Par. 6.1] *Electronic inclinometers* shall *provide the data with sufficient accuracy for a proper assessment of the ships dynamic situation. Minimum accuracy of the measurements* shall *be 5 % of reading or ±1°, whichever is the greater for angle measurements and 5 % of reading or ±1 s, whichever is the greater for time measurements*.

5.2 Acceleration condition

[IMO MSC.363 (92) Par. 6.2] *Actual heel angle and time measurement accuracy* shall *not be unduly affected by other linear or rotational movements of the ship (as e.g. surging, swaying, heaving, pitching, yawing) or by transverse acceleration ranging from −0,8 g to +0,8 g*.

The required acceleration condition, 0,8 g, includes the component of the gravitational acceleration.

6 Test methods and required results

6.1 General

Unless otherwise stated in this document, the requirements of IEC 60945 shall apply to the electronic inclinometer. To ease the term, equipment under test (EUT) will be used to describe an electronic inclinometer system being tested.

The test arrangement shall consist of the following:

— movable arm which enables rotation of the EUT sensor from the zero degree roll angle position (upright) to the maximum roll angle position (90°) to both starboard and port sides;

— display representing other bridge equipment with which the EUT may communicate;

— method of generating and transmitting to the EUT IEC 61162 sentences.

The EUT shall be arranged so that the heel sensors are secured to the moveable arm, the display is readily observable and there is a suitable connection to permit the transmission and receipt of IEC 61162 sentences between the EUT and the inspection equipment.

6.2 Static actual heel angle test

6.2.1 Method of testing and required results

To determine the actual heel angle of the electronic inclinometer statically, the EUT sensor is gradually rotated from the zero degree to the maximum roll angle position on one side and then from zero to maximum on the other side. Outputs of the EUT and the inspection equipment are recorded every 5° of rotation.

Confirm that the difference between the angles recorded by the EUT and the inspection equipment shall be within 5 %, or 1°, of the inspection equipment reading, whichever is the larger.

6.3 Dynamic actual heel angle test

6.3.1 Method of testing and required results

To determine the actual heel angle of the electronic inclinometer dynamically, the EUT sensor is periodically rotated from the zero degree to the maximum roll angle position on one side and then from zero to maximum on the other side. The inspection equipment shall also permit the addition of the maximum expected transverse acceleration, 0,8 g, to the top of the arm (see Annex B for detailed information on the inspection equipment). Before the test, manufacturers shall provide information on the measurement delays in the EUT. Any measurement delay shall be less than 0,1 s.

The comparison of all measured heel angles between the EUT and the inspection equipment is carried out with randomly selected measured two cycle data in the following conditions:

— roll period of 4 s and roll amplitude of 90°;

— roll period of 40 s and roll amplitude of 90°.

The heel angles of the EUT and the inspection equipment shall be recorded at a frequency of no less than 50 Hz.

Confirm that the difference between the angles recorded by the EUT and the inspection equipment shall be within 5 %, or 1°, of the inspection equipment reading, whichever is larger.

6.4 Long-term actual heel angle test

6.4.1 Method of testing and required results

To confirm that an integral calculus error in the measured heel angle does not influence performance, a series of small angle dynamic actual heel angle tests are conducted. The sensor of the EUT is swung periodically under the condition of roll period of 4 s and roll amplitude of 45° continuously, with a rolling period of 4 s, for no less than 1 d using the inspection equipment.

The heel angles of the EUT and the inspection equipment shall be recorded at a frequency of no less than 50 Hz.

Confirm that the difference between the angles recorded by the EUT and the inspection equipment shall be within 5 %, or 1°, of the inspection equipment reading, whichever is larger.

6.5 Roll period test

6.5.1 Method of testing and required results

To confirm that the EUT correctly records the roll period, the sensor is attached to the arm of the inspection equipment and swung 45° to starboard and port. The comparison of all measured rolls periods between the EUT and the inspection equipment is carried in the following conditions:

— roll period of 4 s and a roll amplitude of 45°;

— roll period of 40 s and a roll amplitude of 45°.

Confirm that the difference between the roll periods recorded by the EUT and the inspection equipment shall be within 5 %, or 1 s, of the inspection equipment reading, whichever is larger.

6.6 Connections to other equipment test

The connections to other equipment test shall satisfy the requirements of 4.6.

The interface facilities shall be subjected to the tests specified in IEC 61162-2.

The "HRM" sentence for transmitting the data to VDRs and other external systems is described in Annex C provisionally.

6.6.1 Method of testing and required results

The sensor of the EUT is placed on the top of the arm of the inspection equipment. The sensor is then rotated to simulate roll period of 10 s and a roll amplitude of 10° for more than 60 s.

By monitoring the "HRM" sentence generated by the EUT, confirm that the output is updated at least once per 200 ms.

6.7 Display test

The display test shall satisfy the requirements of 4.4.

Two samples of the display are shown in Figures 1 and 2. Figure 1 is a sample of a traditional type electronic inclinometer display and Figure 2 is a sample of electronic inclinometer display for a dedicated display or integrated into other bridge systems. They are just samples for better understanding of the defined values and they do not prescribe display design of the electronic inclinometer display.

6.7.1 Method of testing and required results

The EUT sensor is secured to the test arm of the inspection equipment. If the EUT will be interfaced with additional systems' displays, it shall also be connected to a representative system so that the output can be monitored simultaneously. The sensor is subjected to the following motions.

a) Incline the EUT sensor 10° to starboard and to port. Confirm by observation that the actual heel angle value is shown on a dedicated display in an analogue form and to an accuracy of not more than ±5 %, or ±1°, of the actual value, whichever is the greater and that the resolution of numeric display is 1°. By monitoring the HRM sentences transmitted by the EUT, and by observing the display of another "test" equipment interfaced to the EUT, confirm that the value of actual heel angle "told" to the integrated displays of other bridge systems also has an accuracy of not more than ±5 %, or ±1°, of the actual value, whichever is greater and that the resolution of numeric display is 1°;

b) Rotate the EUT sensor at the following pre-determined roll periods and roll amplitudes:

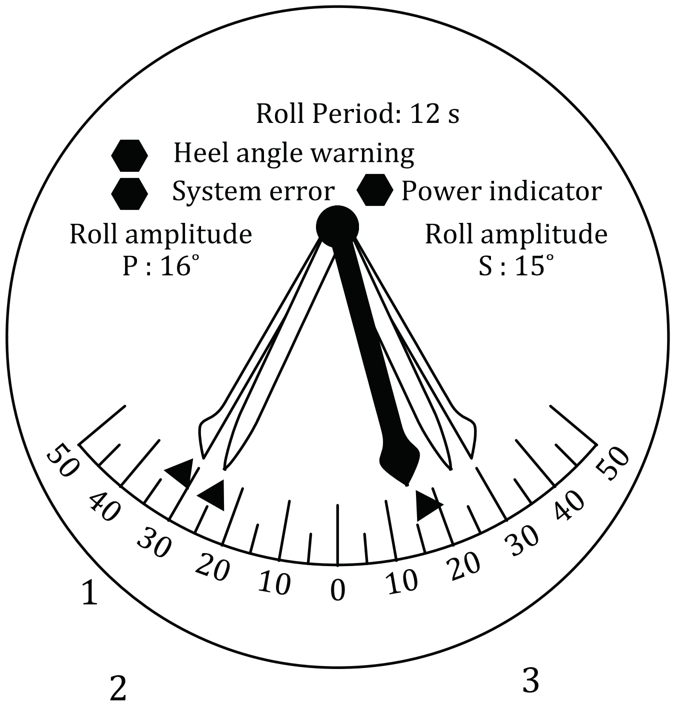
   — roll period of 10 s and roll amplitude 10°;

— roll period of 20 s and roll amplitude 20°;

— roll period of 30 s and roll amplitude 30°.

Confirm by observation that the roll period and roll amplitude values are shown on a dedicated display to an accuracy of not more than ±5 %, or ±1 s, or 1°, of the actual value, whichever is the larger and that the resolution of numeric display is 1° and 1 s. By monitoring the HRM sentences transmitted by the EUT, and by observing the display of another "test" equipment interfaced to the EUT, confirm that the actual values of roll period and roll amplitude "told" to integrated displays of other bridge systems has an accuracy of not more than ±5 %, or ±1 s, or 1°, of the actual value, whichever is the larger and that the resolution of numeric display is 1° and 1 s.

When the measured roll period is less than 4 s, the display should represent the value as "–" and when the period is greater than 40 s, as "++".



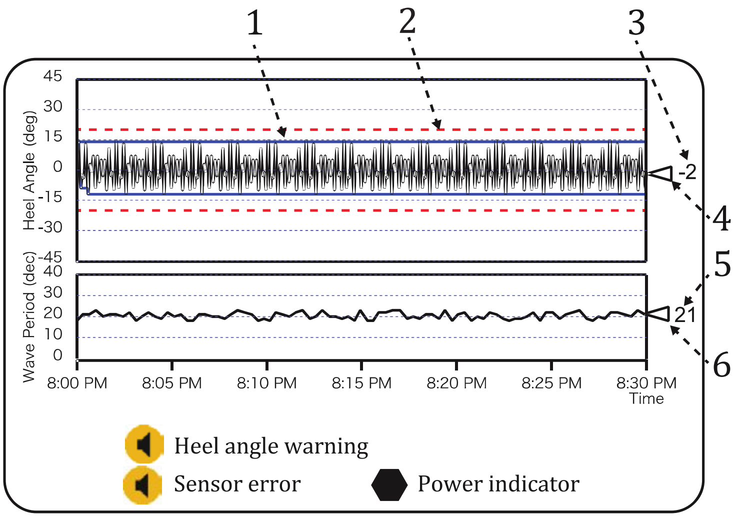
Key

1 roll peak hold value

2 threshold heel angle

3 analogue heel angle indicator

Figure 1 — Example of a conventional head up type electronic inclinometer display



Key

1 roll peak hold value

2 threshold heel angle

3 digital heel angle indicator

4 analogue heel angle indicator

5 digital roll period indicator

6 analogue roll period indicator

Figure 2 — Example of an electronic inclinometer display for an integrated conning display

6.8 Operational alert test

The operational alert test shall satisfy the requirements of 4.5.1.

The electronic inclinometer shall provide an operational alert when it has a function for warning to indicate that a set heel angle has been exceeded.

The operational alert function shall provide display of the warning and ALF sentence to initiate a warning on other bridge systems when the actual heel angle exceeds the pre-set threshold.

6.8.1 Method of testing and required results

Perform the following procedures.

a) Set the threshold value to 20° by a manual input device, if available. Confirm by observation that the threshold value is shown on its dedicated display or an integrated display of other bridge system properly. Confirm by observation that the TXT sentence for informing roll threshold angle (defined in 4.5.1) is transmitted from the electronic inclinometer to other bridge systems to show the pre-set threshold value on the display of the other bridge system.

b) Or set the threshold value to 20° by transmitting a TXT sentence for setting threshold value of heel angle (defined in 4.5.1) to the electronic inclinometer. Confirm by observation that the pre-set threshold value is shown on the display properly.

c) Incline the heel sensor to 30°. Confirm by observation that the electronic inclinometer initiates an operational alert as "active – unacknowledged" warning in compliance with IEC 61924-2 by audible and visible means together with associated descriptive text directly assigned to the function generating the warning on its dedicated display or an integrated display of other bridge system. Confirm by observation that ALF and ALC sentences are transmitted from the electronic inclinometer to other bridge systems to report new warning status (active – unacknowledged) of the electronic inclinometer.

d) Confirm by observation that proper behaviours are executed under the status change of "active – unacknowledged" and "active – acknowledged" and the actions of "silencing" and "continuing" in compliance with IEC 61924-2.

e) Restore the heel sensor to zero degree inclination. Confirm by observation that the warning including visual indication appears continuously and a state of warning is "active – acknowledged".

f) Execute the changing method of the alert state from active to normal. If the changing device is on other bridge system, use the TXT sentence for changing the alert state from active to normal (defined in 4.5.1). Confirm by observation that the warning including visual indication disappears.

6.9 Functional alert test

The functional alert test shall satisfy the requirements of 4.5.2.

6.9.1 Method of testing and required results

Perform the following procedures.

a) Set the electronic inclinometer to a malfunction state. Confirm by observation that the electronic inclinometer initiates a functional alert as "active – unacknowledged" warning in compliance with IEC 61924-2 together with associated descriptive text directly assigned to the function generating the warning on its dedicated display or an integrated display of other bridge system with no audio signal and speech output.

b) Confirm by observation that proper behaviours are executed under the status change of "unacknowledged" and "acknowledged" and the actions of "silencing" and "continuing" in compliance with IEC 61924-2.

c) Recover the electronic inclinometer from the malfunction state. Confirm by observation that the warning including its visual indication disappears after the alert condition is rectified.

6.10 Roll peak hold value test

The roll peak hold value test shall satisfy the requirements of 4.3.3.

6.10.1 Method of testing and required results

Rotate the electronic inclinometer as following conditions:

— roll period 10 s and roll amplitude 10° for more than 60 s;

— roll period 30 s and roll amplitude 30° for more than 180 s;

— stop rotating.

Confirm that the roll peak hold value is shown on a dedicated display and/or HRM sentence is transmitted by the electronic inclinometer to other bridge systems and it includes proper roll peak hold values.

6.11 Reset function of roll peak hold value test

The electronic inclinometer shall provide a manual reset device to initiate reset function with single operator action to users, when it has a function to show roll peak hold values.

The roll peak hold values shall become zero, when the reset function is initiated.

The reset date/time should be recorded and displayed on a dedicated display or an integrated display, when the reset function is initiated.

6.11.1 Method of testing and required results

Push a roll peak hold value reset button of the electronic inclinometer, if available, or transmit TXT sentence (defined in 4.3.3) to the electronic inclinometer to reset the roll peak hold value.

Confirm the following:

— both starboard and port roll peak hold values are set to zero, and/or the reset date/time is set to the time when the reset button is pushed or TXT sentence (defined in 4.3.3) is received;

— TXT sentence (defined in 4.3.3) transmitted by the electronic inclinometer includes proper roll peak hold values and reset date/time.

6.12 Power supply test

It shall be confirmed that the electronic inclinometer is powered from the ship's emergency source of electrical energy, when the ship's main source of electrical energy is unavailable.

7 Installation position

[IMO MSC.363 (92) Par. 11] *The installation position of the sensors of the electronic inclinometer* shall *be recorded and made available for the configuration of the voyage data recorder.*

8 Information

The manufacturer shall provide adequate equipment documentation to enable competent members of a ship's crew to operate and maintain the equipment efficiently.

Annex A
(informative)

Relationship between transverse metacentric stability and measured natural roll period of ships in waves

To help understand the use of measured natural roll period in waves and effective GM (the metacentric height of the ship) in decision making when navigating in rough seas, this annex explains the relationship between stability and measured natural roll period of ships in waves.

Figure A.1 illustrates a transverse cross section of a ship hull and shows restoring roll moment caused by inclination.

As the GM is considered effective in small heel angles from the upright, typically less than about 10°, the restoring moment of roll motion is expressed in Formula (A.1) and the formula of roll motion is expressed in Formula (A.2).

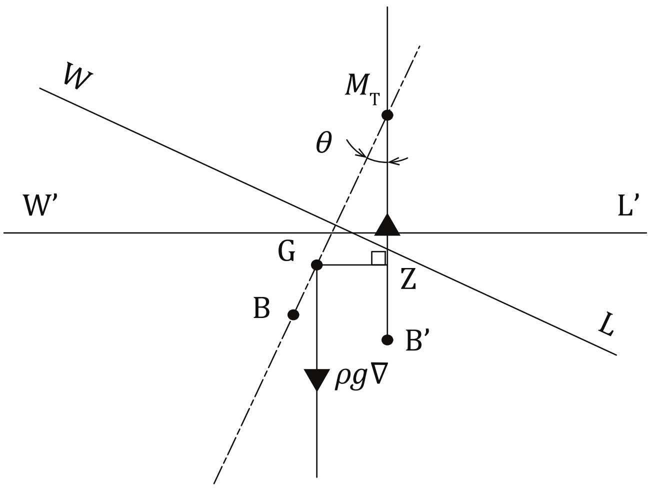


Figure A.1 — Restoring roll moment

$$M = \rho\, g\, \nabla\, \overline{G\, M_T}\, \sin\theta = \rho\, g\, \nabla\, \overline{G\, M_T}\, \theta \qquad \text{(A.1)}$$

where

M	is the restoring roll moment (Nm);
ρ	is the water density (kg/m³);
g	is the gravitational acceleration (m/s²);
∇	is the displacement (m³);
$\overline{G\, M_T}$	is the transverse metacentric height (m);
θ	is the heel angle from the upright (rad).

$$\left(I_x + J_x\right)\ddot{\theta} = -M$$

that is

$$\ddot{\theta} = -\frac{\rho\, g\, \nabla\, \overline{G\, M_T}}{I_x + J_x}\theta \qquad \text{(A.2)}$$

where

I_x is the moment of inertia of roll motion;

J_x is the added moment of inertia of the vessel rolling in water.

Consequently, natural angular frequency and period of the roll motion are expressed as the following formulae respectively.

$$\omega^2 = \frac{\rho\, g\, \nabla\, \overline{G\, M_T}}{I_x + J_x} \qquad \text{(A.3)}$$

where

ω is the natural angular frequency of the roll motion.

$$T = 2\,\pi\,\frac{1}{\omega} = 2\,\pi\sqrt{\frac{I_x + J_x}{\rho\, g\, \nabla\, \overline{G\, M_T}}} \qquad \text{(A.4)}$$

where

T is the natural roll period.

On the other hand, radius of roll motion, k, is defined in Formula (A.5).

$$k^2\, \rho\, \nabla = I_x + J_x \qquad \text{(A.5)}$$

From Formula (A.4) and Formula (A.5), $\overline{G\, M_T}$ is deduced as

$$T = 2\,\pi\,\frac{k}{\sqrt{g\, \overline{G\, M_T}}}$$

$$\overline{G\, M_T} = 4\,\pi^2\,\frac{k^2}{T^2\, g} \qquad \text{(A.6)}$$

In addition, radius of roll motion, k, of merchant ships are approximated with 0,4 times the ship breadth, the formula of $\overline{G\, M_T}$ is simplified as

$$\overline{G\, M_T} = 0{,}64\,\frac{B^2}{T^2} \qquad \text{(A.7)}$$

where

B is the maximum breadth of the ship.

Formula (A.7) is the well-known simplified formula to calculate $\overline{GM}_T$ from the measured natural roll period.

The natural period of roll motion in navigation is obtained from the result of frequency analysis of measured time history of the actual heel angle and then the metacentre height $\overline{GM}_T$ is obtained from Formula (A.7).

However, Formula (A.7) is only applicable under the condition that the roll amplitude is small enough. Generally, the radius of roll motion, k, is changed by hull shape and loading condition. When the roll amplitude is not small enough, the restoring roll moment, M, is also reduced because effective metacentre height $\overline{GM}_T$ becomes significantly smaller than that in small roll amplitude.

Accordingly, we found the following:

— measured natural roll period is considered as an index of the decrease in the metacentre height $\overline{GM}_T$, which reduces the restoring roll moment and metacentric stability of the ship;

— it is not applicable to use as an absolute threshold to alert the loss of metacentric stability by wave, especially in rough sea condition;

— when it is used in decision making when navigating under rough sea condition, decision makers should understand the condition of the validity of Formula (A.7).

Annex B
(informative)

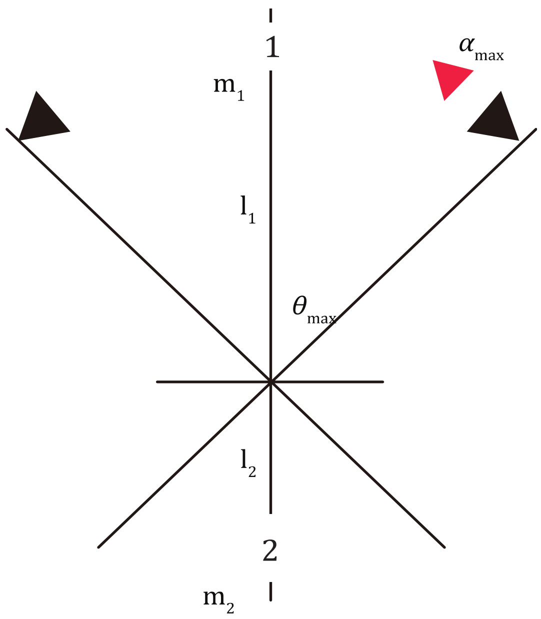
Test facility type test methodology

To realize similar conditions as on-board roll motion, an inverted-pendulum type inspection equipment is available. Figure B.1 shows a schematic diagram of the inspection equipment. A sensor component of tested electronic inclinometers is set on the top of the inspection equipment so that the roll axis of the sensor component is parallel to the axis of the inspection equipment. A counter weight is set on the bottom of the inspection equipment in order to adjust roll period. Roll amplitude can be controlled with a parametric acceleration near the upright position of the pendulum.

Test conditions of roll period required in this document can be attained with appropriate combination of ratios of l_1/l_2 and m_1/m_2, e.g. $l_1/l_2 = 2$ and $m_1/m_2 = 0,2$, give 4 s roll period. Changing these ratios can attain roll period ranging from 4 s to 40 s. This document requires 0,8 g transverse acceleration, which depends on l_1, roll amplitude and roll period, e.g. $l_1 = 2,6$ m, roll amplitude = 30° and roll period = 4 seconds give 0,8 g transverse acceleration at the top of the inspection equipment, including a tangential component of the gravity acceleration.

Outputs of both the inspection equipment and a tested electronic inclinometer are recorded simultaneously and checked according to the requirements in this document.

Resolutions in measurement of the inspection equipment should be no more than 0,2° in angle and no more than 0,04 s in time.



Key

1 sensor component

2 counter weight

Figure B.1 — Schematic diagram of an inverted-pendulum type equipment

Annex C
(informative)

IEC 61162-1 interface for VDR and other systems

C.1 Interface for VDR and other systems

The performance standard of the electronic inclinometer requires the following functions for transmitting data to VDR and other systems.

[IMO MSC.363 (92) Par. 10.1] *Electronic inclinometers shall comprise a digital interface providing actual heel angle information to other systems, e.g. the voyage data recorder (VDR), with an update rate of at least 5 Hz. Electronic inclinometers shall also comprise a digital interface providing the displayed information of roll period and roll amplitude (see 4.3).*

[IMO MSC.363 (92) Par. 10.3] *The digital interface shall comply with the relevant International Standards IEC 61162-1 as amended.*

The sentence of IEC 61162-1 on transmitting data for the electronic inclinometer (HRM) has been defined by IEC and it will be included in the fifth edition of IEC 61162-1, which is scheduled to be published in 2016 or later. Therefore, this annex can be provisionally used to specify the HRM sentence until IEC 61162-1 is released.

The interface for transmitting the sentence is according to IEC 61162-2.

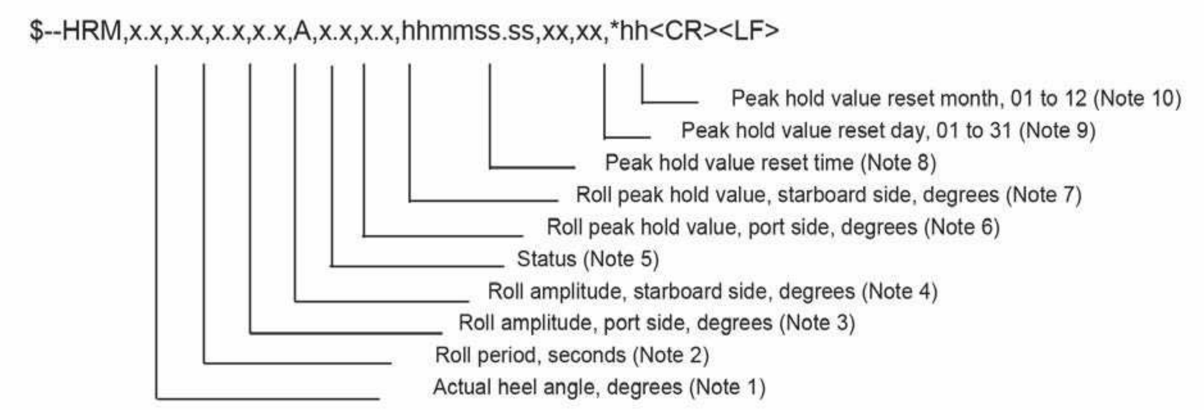
C.2 HRM-heel angle, roll period and roll amplitude measurement device

This sentence is used to provide the actual heel angle, roll period and roll amplitude of an electronic inclinometer to VDRs and other systems. Update rate for this message should be at least 5 Hz.

This sentence optionally provides roll peak hold values and their reset time as well. Roll peak hold value is the value indicated by friction pointers of conventional pendulum inclinometers.

In addition to the requirements of IMO performance standard of electronic inclinometers, roll peak hold values may also be indicated on the displays of an electronic inclinometer. Roll peak hold value is the maximum absolute value of roll amplitude of port side and starboard side from the last reset time of peak hold value. The roll peak hold values are indicated as the value of the friction pointers of pendulum inclinometers and used for decision making in case of sailing under a severe weather condition. The optional values are provided for indicating information on roll peak hold values on dedicated displays or the other displays of integrated bridge systems.

NOTE Refer to IEC 61162–1 for possible later versions of these sentences.



NOTE 1 Actual heel angle, momentary angle of roll referenced to a levelled ship to port or starboard side (positive value starboard, negative value port).

NOTE 2 Roll period, time between successive maximum values of heel angle to port over starboard and back to port (or the other way round).

NOTE 3 Roll amplitude of port side as positive value, maximum value of heel angle to port side of the latest motion.

NOTE 4 Roll amplitude of starboard side, maximum value of heel angle to starboard side of the latest motion.

NOTE 5 Status, A = data valid, V = data invalid.

NOTE 6 Roll peak hold value of port side, maximum value of heel angle to port side of the motions measured from the last reset with a minimum resolution of 1°. This shall be a null field when data is not available.

NOTE 7 Roll peak hold value of starboard side, maximum value of heel angle to starboard side of the motions measured from the last reset with a minimum resolution of 1°. This shall be a null field when data is not available.

NOTE 8 Peak hold value reset time, time when the peak hold values are reset, UTC hour, minute and second Decimal point and fractions of the seconds shall not be used. This shall be a null field when data is not available.

NOTE 9 Peak hold value reset day, day when the peak hold values are reset, UTC day. This shall be a null field when data is not available.

NOTE 10 Peak hold value reset month, month when the peak hold values are reset, UTC month. This shall be a null field when data is not available.

Bibliography

[1] IEC 61162-3, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 3: Serial data instrument network*

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[3] IMO resolution A.694 (17), *General requirement for shipborne radio equipment forming part of the global maritime distress and safety system (GMDSS) and for electronic navigational aids*

[4] IMO resolution MSC.302 (87), *Performance standards for bridge alert management (BAM)*

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[6] IMO resolution MSC.363 (92), *Recommendation on performance standards for electronic inclinometer*

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